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Magnetic fields and large scale structure in a hot Universe

III. The Polyhedric Network

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Abstract. We provide a new tool to interpret the large scale structure of the Universe. As suggested in Paper II, energy density filaments could have been produced by subjacent magnetic flux tubes when the Universe was dominated by radiation. In more recent time epochs, small scale filaments have evolved in a complicated way, but large scale filaments have probably survived and should be identified with present observed matter filaments of clusters. A primordial magnetic field lattice made up of magnetic flux tubes would then have originated a matter lattice made up of cluster filaments. Taking into account some restrictions in the magnetic field configuration we speculate what type of matter network this would have generated. The simplest lattice is made up of octohedra connected at their vertexes, reminding us of a structure of superimposed egg cartons. The vertexes would correspond to large superclusters, which would therefore have eight filaments emerging from them. Some observational evidence is found in the Local Supercluster, which is spider-like, with eight legs.

Key words: Magnetohydrodynamics (MHD) – relativity – cosmology: large-scale structure of Universe

1. Introduction

In Paper I (Battaner, Florido and Jimenez-Vicente 1997) and Paper II (Florido and Battaner 1997) we suggested that primordial magnetic flux tubes have generated radiative energy density filaments throughout the radiation dominated era. As filaments are very frequently present in the observed large scale structure today, it is here considered that contemporary matter filaments could be identified from these early radiative filaments.

Under this assumption, present large structures would have inherited the topological structure imposed by the properties of magnetic fields. This is the goal of this paper, i.e. by assuming that filaments are magnetically induced condensations of matter and that they are the pieces with which the Universe is made up, to identify what observational properties large scale structures would possess.

Filaments are often found in many astrophysical systems, such as the Sun and the interstellar medium, and are often interpreted as being magnetically induced. We propose here a similar interpretation for galaxy cluster filaments.

The model presented in Papers I and II, considers a time period between Annihilation and Equality; therefore, the matter, radiation and magnetic field configuration which had been predicted cannot strictly be compared with present large scale structures. To make such a comparison valid, the model should be extended to the present, considering epochs in which the evolution of filamentary structures is much more complicated. But the development of a single model, suitable for so many different epochs is not at present practical. It is however possible and tempting to qualitatively predict what kind of structures would now arise from those theoretically predicted pre-Equality structures. There are two main arguments which make this prediction reasonable:

-As discussed in paper II, the further evolution of the structures is subject to three effects which were considered negligible in earlier epochs: viscosity and heat conduction as the fluid becomes imperfect, the amplification of magnetic fields by dynamo effects or ejections from galaxies, and non-linear effects. However, all these processes only affect small

scale structures. Large scale structures, therefore, can be considered unaltered in recent epochs, and have evolved in a simple way, just being diluted by expansion, as described, for example, in an Appendix to Paper I.

-At Equality, filamentary distributions of radiation and matter had already formed. By Recombination, matter was free to further concentrate around previous filamentary potential wells. We must therefore consider the evolution of these early matter structures, even independently of the subjacent magnetic fields which created them. The evolution of pre-recombination matter structures is a subject in which considerable experience has been attained in recent years, and is considered, for instance in the interpretation of CBR anisotropies. Again, the evolution of very large scale structures is much simpler, as it is linear. Magnetic fields could evolve in different ways and might even affect the evolution of matter distribution, though probably not in a wholly unpredictable way.

It should not be forgotten, on the other hand, that our analysis in Papers I and II, was developed for a hot particle fluid, and in particular for photons before Equality. However the equations could describe actual structures at present, if hot dark matter were dominant.

We are therefore aware that our discussion is qualitative and speculative, but nevertheless interesting, as it could open new ways of interpreting large scale structures. Let us therefore assume that the present large scale structures are larger than but essentially identical in shape to the parent pre-Equality filamentary structures.

2. Magnetic restrictions to the large scale structure

Independently of the epoch in which primordial magnetic fields were generated, they must fulfil a restriction: $\nabla \cdot \boldsymbol{B} = 0$. Magnetic field lines are either straight lines when viewed at large scale or they form loops. The first possibility must be excluded if the Cosmological Principle is maintained.

Loops can be made from filaments, with plane polygons being the simplest possibility. Three-dimensional structures made up of polygons are polyhedra. From the observational point of view, the polyhedric nature of the Universe is far from demostrated, but this possibility is by no means in disagreement with observations (Broadhurst et al., 1990; Einasto et al 1997a,b). We should look for the simplest polyhedric structures compatible with the absence of sources and the loss of magnetic field lines.

The Cosmological Principle would require either isolated polygons or polyhedra with random orientations or period like structures with the basic polyhedra in contact, forming a network. As isolated structures are not suggested by observations, we concentrate on the network structure. Assuming the structure is periodic and three-dimensional, a crystallographic approach seems reasonable.

Of course, we are not proposing that the Universe is a pure crystal. More irregular and imperfect forms would actually be produced, reminding us more of a form structure than a crystal, but a perfect network is an adequate zero-order theoretical description. A network is a description of the large scale structure commonly found in the literature. However, the edges of the network polyhedra now have a direction, that of the parent magnetic field.

Magnetic field lines connect filaments and there exists in principle the possibility that they have a complicated contour travelling through different basic polyhedra. However, the simplest option is to close the loop within only one polyhedrum or even, within a single face.

The simplest structure would be that when all edges, all faces and all vertexes are equivalent. This implies that the magnetic flux at any of the vertexes vanishes. Any magnetic field line reaching a vertex through one of the edges must quit the vertex through one of the other equivalent edges. Any arrow of the magnetic field entering a vertex must exist. This is a severe restriction as it implies that the number of edges converging at a vertex must be "even".

The simplest case is when the basic polyhedra has four edges converging at a vertex (2 is impossible and 3 is "forbidden"). For example, out of the five regular polyhedra, the octahedron has this property. The icosahedron also has an even number of edges at a vertex but it is less simple.

Octahedra do not fill up the whole space, i.e. they cannot produce a Bravais lattice. Some minerals have lattices made up of a combination of octahedra and tetrahedra, but this possibility is ruled out here because only three edges converge at a tetrahedron vertex.

When considering octahedra, or any other less simple polyhedra, in contact, they may share a filament merged from two contacting edges. In this case, we assume that both edges have the same direction of magnetic field, because otherwise reconnection of magnetic field lines would take place. This greatly restricts the possible "a priori" ways of putting the basic polyhedra in contact.

We therefore conclude that the simplest lattice is made up of regular octahedra. In the next section we will consider which octahedron lattice is compatible with all the magnetic and simplicity requirements.

There are also some interesting possibilities which do not fulfil all of our requirements, in particular the requirement that all edges and vortexes should be equivalent. Let us describe one of the most interesting, even if it was disregarded as the simplest one. There are only fourteen kinds of simple space lattices (Bravais lattices). Among them, those named

body centred structures are the most likely to optimize the above restriction of four edges converging at a node of the unit cell (see figure 1).

Note that the same is true for tetragonal and orthorhombic body-centred structures, that is, the configuration of directionality accepts dilation operation along the orthogonal axis of the cell.

Fig. 1. Body centred cube, showing convergent and divergent vertices and the central point

In this particular body-centred cube all edges are equivalent. Not all vertexes are equivalent. Convergent vertices are those in which magnetic fluxes from the three convergent edges converge. Divergent vertexes are those in which magnetic fluxes from the three convergent edges diverge. To ensure $\nabla \cdot \boldsymbol{B} = 0$, the straight line joining a vertex and a central point, must support a magnetic flux three times the flux of one of the edges. When these individual body centred cubes are assembled to make a complete tessellation, it is easy to calculate that not all vertexes and central points are equivalent. Taking the magnetic flux in each individual edge as unity, the magnetic flux entering (or exiting) a vertex is 24. However, at the central point it is only 12. Vertexes and central points are not equivalent, nor are convergent and divergent vertexes equivalent. The lattice containing both types of vertexes is, however, simple, like a salt crystal.

3. The “Egg-Carton” Universe

Therefore, eliminating the body-centred cubic solution, we have looked for octahedric structures with all vertexes and edges completely equivalent. After trials, the only possibility was found to be the one shown in fig. 2. This consists of a primitive cubic lattice in which an octahedron is located at each lattice node and then exploded until it connects with its six nearest neighbours through the vertexes. In this configuration eight edges converge at any one vertex. In addition, all the edges and vertexes are equivalent, supporting the same magnetic flux. Note again that this configuration maintains the topological properties when a dilation operation along the ortogonal axis converts the octahedron shape into a bipyramid. This lattice is built up from octahedra joining only at their vertexes.

This lattice reminds us of a structure of superimposed “egg-cartons”, with the spaces for the eggs representing the voids constituting the large scale structure.

Fig. 2. Lattice of octahedra contacting at their vertexes

It is difficult to find observational evidence to check this prediction, due to the relative scarcity of data available today about the large-structure of the Universe. Our edges are super-dense photon filaments which after recombination become matter filaments. At those places where edges or filaments converge we would have still larger concentrations of matter. Filaments are made up of superclusters (e.g. Coma) or simply connect superclusters (Haynes & Giovanelly 1986, Tago, Einasto & Saar 1984).

It is an observational fact that filaments are predominant (Gregory & Thomson 1978; Joeveer & Einasto 1978; Tully & Fisher 1978; Lapparent, Geller & Huchra 1986) with voids in between, and most of them connect superclusters (Gott, Weinberg & Melott 1987).

But the prediction here would be that *eight* filaments join each other in a supercluster or in a non-filamentary region in which the matter concentration is specially high. Are these superclusters, from which eight filaments diverge, in the actual structure?

Einasto (1992) and Einasto et al. (1984) compare the structure of the Local Supercluster with a spider. Spiders have eight legs and Einasto’s spider is no exception. Examining figure 18 in Einasto’s (1992) review it is observed that precisely eight filaments diverge. Einasto’s spider has eight legs.

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